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A Comprehensive Eco-friendly Total Waste Management Solution for Cosmopolitan Cities like Coimbatore with Resultant Pollutant-less Surface Water and Reduced Demand on Ground Water Accompanied with Greener Input for Some Polluting Manufacturing Processes

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ABSTRACT
Pollution is one of the biggest problems faced by the world nowadays. The impact of pollution on life is enormous. So far several measures are being taken to face the huge challenge. The causes for pollution are being studied and the human race is trying to combat pollution in a scientific manner. In the present research work, some of the causes of pollution and its effects are studied and found that improper management of waste is one of the important causes for pollution around the world. The main objective is to propose a comprehensive waste management plan for cosmopolitan cities like Coimbatore in a view to achieve sustainable environment based on greener waste management.

Key words: Pollution, Effects of Pollution on Life, Eco-friendly, Cost effective, Comprehensive, Total Waste Management Plan, Cosmopolitan Cities, Coimbatore, Pollutant-less Surface Water, Reduced Demand on Ground Water, Greener Input, Greener Environment.

INTRODUCTION

Improper or unscientific management of waste leads to pollution and unhealthy environment. The present research work aims at finding a comprehensive solution for cosmopolitan cities like Coimbatore through eco-friendly means. One such research is successful which was done previously on dairy effluent by converting it into useful biosolids, an input material for the production of an industrially important enzyme named protease. Similar techniques are analysed in the present work to find a solution that helps in creating a pollution free and sustainable environment.

POLLUTION

Any undesirable change in the environment causes pollution. Rapid deforestation, biodiversity and habitat loss, crop failure, desertification, land degradation, unhealthy drinking water, noise pollution and sanitation problems are faced by the cities of developing countries like India [1, 2]. Environmental pollution caused due to unsustainable human activities results in major health problems [3]. Environmental pollution is considered to be a worldwide problem which can affect the healthy living of human to a greater extent [4, 5]. Pollution is made by human activity as well as by natural means [5, 6]. Pollution is especially high in thickly populated areas and industrial areas. Increased global concern is on the public health effects due to environmental pollution [7]. Increased levels of pollution cause excessive damage to human and animal health, plants and trees including tropical rainforests and wider environment [8].

TYPES OF POLLUTION

Pollution can be classified into three types which occur most commonly. They are

i. Pollution of air
ii. Pollution of land and
iii. Pollution of water.

Air pollution and its effects on human life

Pollution free air is required to maintain good health and if air is polluted, it affects the life of living organisms seriously. There are hazardous substances present in the polluted air that causes general health hazards [9]. Some of the major pollutants of air include particulate matter, PAHs, lead, ground level ozone, heavy metals, sulphur dioxide, benzene, carbon monoxide and nitrogen dioxide [10]. The effects of air pollution are listed below in alphabetical order.

- Asthma [11, 12, 13, 14, 15, 16],
- Asthma exacerbations [17, 18, 19, 20],
- Cancer [10, 21],
- Cardiovascular problems [10],
- Disruption of endocrine [22, 23] and reproductive and immune systems [10, 22],
- Headache and dizziness [22],
- Irritation of eyes, nose, mouth and throat [22],
- Neurobehavioral disorders [24, 25, 26, 27, 28],
- Premature death [10],
- Reduced energy levels [22],
- Reduced lung functioning [22, 29],
- Respiratory disease [10, 30],
- Respiratory symptoms [22, 31].

Water pollution and its effects on human life

The availability of potable water is essential for survival and well being of living organisms on earth. But now, it is clear that water is being polluted throughout the world and pure water may become unavailable very soon. There is no doubt that water pollution affects the health and quality of soil and vegetation [32]. The WHO states that one sixth of the world's population approximately 1.1 billion people do not have access to safe water and 2.4 billion lack basic sanitation [10]. The poor quality of water causes health hazard and death of human being and aquatic life, also affects the production of various crops [2, 33,]. Water is polluted mainly because of untreated industrial effluents and sewage water [2]. The effects of water pollution are as follows.

- Alzheimer's disease,
- Amoebiasis,
- Ascariasis,
- Cancer,
- Damage to the DNA and even death,
- Damage to the nervous system,
- Different type of damages on babies in womb,
- Giardiasis,
- Heart disease,
- Hookworm,
- Hormonal problems that can cause developmental and reproductive disorders,
- Liver and kidney damage,
- Multiple sclerosis,
- Non-Hodgkin's Lymphoma,
- Parkinson's disease and
- Typhoid [34].

Apart from these, the effects of polluted beach water containing pathogens include stomach ache, encephalitis, Hepatitis, diarrhoea, vomiting, gastroenteritis, respiratory infections, ear ache, pink eye and rashes [34].

Land pollution and its effects on human life

Land is polluted mainly because of dumping waste without proper treatment. Agriculture lands are being polluted because of excessive use of chemical fertilizers and pesticides. Such chemical substances enter the ecological cycle and pose many threats to the life forms. It is estimated that PCBs, dioxins, DDT, and a number of other organochlorine pesticides are commonly found in human breast milk and adipose tissue [35, 36]. Chemicals present in the soil get absorbed by the plants and thus the chemical substances enter the food chain. Therefore, land pollution is considered as one of the major forms of environmental disaster [3] and one of the main causes of environmental pollution is the improper management of solid waste [7].

It is evident that much of the pollution is caused by human activities. Therefore, the responsibility to help nature to restore itself falls on the human race. Eco-friendly approach is required to protect the environment from deterioration. The usage of natural resources must be controlled to reduce the impact on environment; reusing the items before disposal and recycling of the generated waste must be practiced as far as possible.

RECYCLING OF WASTE

It is impossible to stop generation of waste due to human activity. Therefore, recycling would be the best means to attain greener environment [37].

TYPES OF WASTE

Waste can be divided into two types based upon their degradability. They are
i. Organic waste
ii. Inorganic waste.

Organic waste and inorganic waste

Organic waste is generated from organic sources such as municipal sewage, kitchen waste, agricultural waste and animal waste. Organic waste is biodegradable. Inorganic waste is not easily biodegradable in the environment and such wastes are either harmful or harmless to the environment. Adequate knowledge should be possessed about the type and nature of waste before recycling. Therefore, composition of waste must be studied in detail before treatment to ensure complete biological degradation.

RECYCLING ORGANIC WASTE

Organic waste can be recycled in many ways. Some of the processes are discussed here.

Composting or aerobic process

Composting is a simple and fast process of treating waste in open environment. This type of waste treatment has several positive effects like stabilization of organic matter, elimination of unpleasant odor and reduction of pathogenic microorganisms to an acceptable level. The simplest way is composting of the dehydrated fresh digestate in a static or temporarily turned-over pile [38].

Vermicomposting

Bhiday estimated that nearly 700 million ton organic waste is generated annually in cities and rural areas of India, that is either burned or land filled [39]. Such organic waste can be recycled by vermicomposting. Vermicomposting is a simple biotechnological process where organic waste is composted with the help of earthworms to enhance the process of waste conversion and produce a better end product [40]. The advantage is that the process is much faster than composting. Earthworms eat up the organic waste and digest the waste and finally a natural fertilizer is egested. This is called as vermicompost which is rich in microbial activity, plant growth regulators, and also fortified with pest repellence attributes as well [41, 42].

Anaerobic digestion and biogas production

Organic waste is digested by anaerobic microorganisms naturally in the wet environments where there is absence of oxygen like swamp, bottom of lakes, inside wastewater net pipes and landfill sites [43]. Reports are available for the use of the evolved gas from anaerobic digestion at very early period. Richard Mattocks pointed in his report that the ancient Chinese allowed vegetables and manures to rot in a closed vessel and experimented with burning the gas given off [44]. Biogas is a mixture of gases containing Hydrogen (H_2), Nitrogen (N_2), Hydrogen Sulfide (H_2S), Carbon monoxide (CO), Ammonia (NH_3), Oxygen (O_2) and water vapor (H_2O) in trace amounts [45], while methane (CH_4) and carbon dioxide (CO_2) are the main components, where the ratio of methane ranged between 50 - 80% and the ratio of carbon dioxide range is 20 - 50%. After anaerobic digestion, the digestate can be utilized probably after an additional treatment. Most often, the digested substrate is used as a fertilizer as in the case of farm waste substrate [38]. Figure 1shows the production of biogas from organic waste and substrate utilization.

RECYCLING INORGANIC WASTE

Inorganic waste like glass, polythene, aluminium, plastic and paper are recycled to produce new products of their respective class. The ink from the waste paper is removed with the help of water and chemicals prior to pulp formation. Then the pulp is cleaned and processed to fibers which are made into paper again. Aluminium waste is ground to small chips and melted to form solid bars of aluminium. New aluminium cans are formed from such bars. Waste glass is ground in to tiny pieces called cullet which is melted and cooled to form glass again. Inorganic waste, if dumped excessively on land would result in the emission of green house gases and pollution of surface and ground water. Soil is polluted and its fertility is lost.

WASTE MANAGEMENT SYSTEM

Solid waste management is connected with the control of waste generation, collection, transfer and transport, processing and disposal of waste in such a way that the waste management agrees with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations [46]. It also includes all administrative, financial, legal, planning and engineering functions involved in finding solution to problems of solid waste thrust upon the community [46].

CATEGORIES OF SOLID WASTE

Solid waste can be categorized based on source as shown in table no.1.

WASTE MANAGEMENT IN INDIA

Approximately 1, 60, 000 Metric Tons of municipal solid waste is generated in India everyday [47]. It becomes a great concern if the waste is not treated appropriately before dumping. The solid waste management system comprises of three major steps namely,

i. collection
ii. transport and
iii. disposal

Collection

The common collection methods in India include door to door collection and Community method. In community bin method, the bins are not properly placed, not designed as per quantity of waste generated and are not covered. This resulted in problems like odour, stray dog nuisance and unaesthetic appearance [48]. In door to door method, the worker collects the waste and put it in separate bins which are transferred into large storage containers. The system has been adopted in Chennai [49] and has improved the efficiency of collection of segregated waste.

Transfer and transport

Transfer of waste is from either the pushcarts to trucks or from bins to truck. Transportation of waste is carried out by the municipalities employing vehicles like open trucks, tractor-trailers, tipper trucks and dumper placers [47].

Recycling of waste

Rag pickers mainly help in carrying out the recycling process in India and they play a vital role in the economy of solid waste recycling process [50].

Disposal

Uncontrolled land filling has been mainly adopted for ultimate disposal of municipal solid waste in India thereby, causing health, environmental and aesthetic hazards [51].

Different waste management methods and techniques are used in different regions of the world. A brief discussion on the methods utilized in different regions would help in better understanding of the system.

WASTE MANAGEMENT IN SOME OF THE WORLD'S CITIES

Studying the type of waste management system followed in some of the cities of the world would provide an outlook on the management system around the world. The comparative study on waste management of world cities brings out common elements of waste management, while encouraging every city to develop its own individual system suitable to its economy, demography and culture and to its institutional, environmental and financial resources [52]. A study done by Wilson et al, presents waste management system of 20 cities chosen from six continents which serve as reference cities. The study is done to get a broad understanding of what solid waste management is, and what it can mean for cities, whether they are located in low, middle or high income countries [52].

The selection of cities is based on criteria such as to demonstrate a range of urban solid waste and recycling systems across the six inhabited continents and illustrate how solid waste management works in practice in tropical and temperate climate zones, in small and large cities, in rich and poor countries, and at a variety of sizes and scales [52]. Among the 20 cities selected, there are three cities with a population over 5 million, and three with less than 100,000 [52]. Table no. 2 shows the population, income levels, municipal solid waste generation and composition in the reference cities.

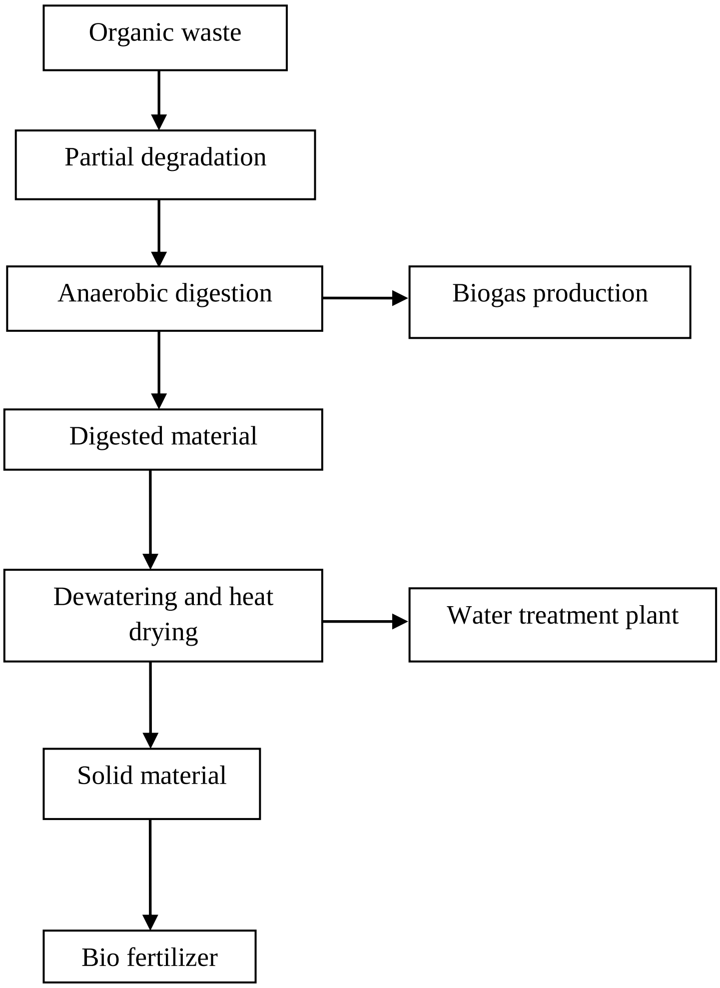

Figure 1: Biogas production from organic waste and substrate utilization.

Table 1: Solid Waste categories based on source

Source	**Typical facilities, activities or locations where wastes are generated**	**Types of solid waste**
Agriculture	Field and row crops, orchards, vineyards, diaries, feedlots, farms, etc	Spoiled food wastes, agricultural wastes, rubbish and hazardous wastes
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc	Industrial process wastes, scrap materials, etc.; non industrial waste including food waste, rubbish, ashes, demolition and construction wastes, special wastes and hazardous waste.
Commercial and institutional	Stores, restaurants, markets, office buildings, hotels, auto repair shops.	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes, etc.
Municipal solid waste	Includes residential, commercial and institutions	Special waste, rubbish, general waste, paper, plastics, metal, food waste, etc.

Source: Hester, R. E. & Harrison, R.M., 2002.

Waste generation

The cities in the lowest-income countries from table no. 2 show waste generation in the range 150-250 kg/capita/year while, those in middle income countries generate 250-450 kg/capita/year of waste and those in high income countries generate 450-650 kg/capita/year of waste. Belo Horizonte in Brazil and Managua in Nicaragua have a relatively higher generation rates, which may be a general characteristic of Latin America [52].

Waste composition

Table no. 2 also provides comparative data on waste composition.

- Paper percentages appear relatively low, with 14 cities reporting 3-10% and only 4 reporting more than 15% (in Mauritius, Netherlands and the USA) [52].
- Plastic levels seem more evenly spread; just two cities report less than 5%, while 10 cities are in the range 5-10% and eight are between 11-17%. Rotterdam reports the highest figures, but those for Curepipe, Mauritius, Quezon City, Philippines, and Nairobi, Kenya, are unexpectedly higher than for both the US cities [52].
- Organic levels generally follow expectations, with 10 of the 'southern' countries reporting 50-80%, and the five cities in Europe, North America and Australia reporting less than 35%. However, there are exceptions, which point to the importance of local conditions and practices: Bamako in Mali and Lusaka in Zambia collect around 50% of 'other' components, which are identified as sand, grit and probably soil, which reduces the relative organic levels [52].

Waste management and recycling

Table no. 3 shows the waste management and recycling system in reference cities. Waste collection and sweeping are included under public health category, while disposal, land filling and incineration are included under environmental protection. Recovery of resources is considered based on the recovery of materials by formal and informal sectors.

Waste disposal

With the exception of Bamako, all the cities are controlling a minimum of 65% of waste going to their formal disposal sites, with 14 out of 20 cities controlling 100% while, Delhi, Nairobi, Managua, Canete and Moshi are five of the 20 cities that rely entirely on controlled disposal [52].

Rotterdam and Kunming are the only examples from the 20 cities that rely heavily on incineration. Ghorahi in Nepal is an interesting example of a small municipality in India, a developing country with very limited institutional and financial resources, which has however managed to conduct scientific studies, identify a very suitable site that is accepted by the general public, and develop a well-managed state-of-the-art facility [52].

Resource recovery

Rotterdam and Kunming are the only two reference cities that recover energy from their municipal waste while, all other reference cities focus on material recovery. In Bamako and Mali raw organic waste is sold to grain farmers as *céréaliculteurs* while, partly decomposed organic waste called *fumure*, or *terreau* is sold to the vegetable farmers in the flood plain of the Niger River [53].The U.S. cities of San Francisco and Ithaca in Tompkins County, and the Australian city of Adelaide are reaching high recovery rates ranging from 55 to 70%. This is due to their strong commitment to 'zero waste' policies and accompanying schemes for separate collection of organic waste and recyclable waste, which have in part developed as a way to divert waste from costly disposal at local state-of-the-art landfills [53].

The study has found that municipal organic waste is a heavily under-utilized resource. While the organic fraction constitutes 60-80% by weight of municipal waste in most reference cities [52], there have been only modest initiatives to recover its value. Study of the 20 reference cities shows that it is possible to make progress in tackling solid waste management despite legal limitations [53].

With the above discussion, it is clear that there is no one-to-one perfect method for all. The main focus is to propose an effective integrated waste management system. In most of the systems followed around the world, the final waste product is either land filled or incinerated. This research work makes an effort to utilize the final waste product as input for energy/material recovery instead of dumping. This would result in a much greener environment.

COIMBATORE, A TYPICAL COSMOPOLITAN REFERENCE CITY

Coimbatore is a growing city with moderate climatic condition, where pollution is also on the rise. With a large area, a lot of up coming industries and increasing population, the city generates greater amount of waste everyday. River Noyyal, which carried clean water once through the city, is highly polluted because of improper waste disposal. Coimbatore thus faces urbanization problems like any other cosmopolitan city and if a consolidated and sustainable solution is to be found for waste management of Coimbatore city, it is like finding a remedy for all such cosmopolitan cities around the world. Therefore a case study on the city has been done in order to propose a suitable plan.

CASE STUDY ON COIMBATORE

Coimbatore is the third largest city in Tamil Nadu state and is located on the banks of river Noyyal. It is known as `The Manchester of South India' as it is the home for number of textile mills and small scale

engineering units. The city is well connected to its region by rail, road and air [54].

CLIMATE AND RAINFALL

The average maximum and minimum temperatures are 39.6° C and 17.3°C, respectively. The average rainfall per annum is around 495 mm [54].

POPULATION

The population of Coimbatore City is 34, 72,578 as per the 2011 census. The population growth recorded in 2011 for the decade was 18.46%. Same figure for 1991-2001 decade was 16.96% [55]. Table no.4 gives the comparison between 2011 and 2001 Coimbatore census, from which the population growth rate can be interpreted.

COIMBATORE LPA POPULATION

The Local Planning Area of Coimbatore comprises of two municipality and 12 Town Panchayats. The Municipal Corporation serves 72 wards within the corporation limits, covering an area of 105.6 sq. Km. The City is divided into four Zones namely, North Zone, South Zone, West Zone, and East Zone with 18 wards each. Coimbatore is the largest industrial center after Chennai, and is a part of the Coimbatore-Tirupur–Erode Industrial corridor [54].

WATER SUPPLY AND SEWERAGE

The Tamil Nadu Water Supply and Drainage Board (TWAD) is responsible for providing water supply and sewerage facility in the state. However, in case of Coimbatore, the system is being maintained by the city Corporation [54].

ENVIRONMENTAL PROTECTION

The Tamil Nadu Pollution Control Board (TNPCB) is responsible for environmental protection and enforcement of rulings related to the same, passed by competent authorities.

PUBLIC HEALTH DEPARTMENT

The department is headed by City Health Officer, and is responsible for ULB services such as Solid waste management, public health related works like malaria control, family planning, mother and child health care, birth and death registration etc, and other government assisted programs related to health and poverty reduction and awareness programs. The City Health Officer assisted by the Health Inspectors and Sanitary Inspectors, is responsible for services of Solid waste management and Malaria Control activities [54].

Functions of public health department include

- Solid Waste Management
- Maintenance of Maternity Homes and Dispensaries
- Public Health [54].

WATER SUPPLY

Coimbatore gets water supply from both surface and underground sources.

Surface Sources

Coimbatore receives water from two sources, situated at Siruvani and Pilloor. The sources are maintained by the Tamil Nadu Water Supply and Drainage Board, and are located at a distance of 36 km and 95 km from the city, respectively [54]. Table no. 5 states the surface source details.

Underground sources

There are 436 open wells / bore wells in operation to supplement to the non-potable water requirement where, 250 bore wells / open wells are maintained by private operation and the rest are being operated by the engineering department of Coimbatore Corporation [54]. Table no. 6 gives the underground source details.

RAIN WATER HARVESTING PROGRAM

Corporation has made water harvesting compulsory for new developments irrespective of usage of the building. In addition to this, an NGO called SIRUTHULI in association with the city Corporation developed more than 150 rain water harvesting structures, in road margin as well as in open spaces to infiltrate rain water in to the ground [54].

The key issues identified in water supply are

Source Shortage in summer: Siruvani supply reduces every summer and hence it is a big concern.
Contamination of water: Frequent contamination occurs due to the close vicinity with sewage lines [54].

SEWARAGE SYSTEM

The sewerage system in Coimbatore covers an area of 23.10sq. km. The area covered by this underground sewerage system is divided into three zones. Zone I covers approximately 7.5 sq. km, while the balance 15.6sq. km of area is covered by zones II and III. The three zones collectively discharge 36.04 MLD of sewage, which is carried by 162 km of sewer line. The sewage from Zone I is collected by 5 main sewers, which run across Valankulam tank, and is discharged at the treatment plant at Ukkadam. The treatment facility at Ukkadam broadly consists of screen chamber, grit chamber, settling tank, sludge digestion tank and sludge drying bed. The sewage from zone -II is collected and pre-treated at the treatment plant at Ukkadam from where it is pumped to Vellalore for final treatment and disposal. The sewerage system for zone-III collects the sewage at the pumping station at Nanjundapuram from where it is discharged to the sewage farm at Vellalore. The farm at Vellalore covers an area of 655 acres. The sewerage system covers three zones, with two disposal sites, one each at Ukkadam and Vellalore and 2 pumping stations, one at Ukkadam and the other at Nanjundapuram [54].

SEWAGE TREATMENT PROCESS

The sewage from Zone I and II is collected in the equalization tank at Ukkadam for equalizing the daily variations of flow from time to time to obtain uniform flow continuously. There are 2 equalization tanks of 50m x 40m each with a total detention time of 8 hours. The sewage is pumped from Ukkadam through 700, 600 and 500 mm pipes with three 75 HP sets to Vellalore for treatment. The treatment work at Vellalore consists of an anaerobic lagoon of 5 to 6 day storage. Sewage from Zone III is collected at Nanjundapuram in equalization pond of 8 hour detention time. The sewage at Nanjundapuram from Zone III is pumped by three number of 150 HP pump sets though 600 mm force main to a total length of 4570m from Nanjundapuram to Vellalore. The treatment works available for Zone III at Vellalore provides an anaerobic lagoon with detention time of 5 to 6 days. The capacity of the lagoon is 44,700 m^3. The two lagoons are not used fully since there is insufficient flow for treatment [54].

The issues identified in under ground drainage sysytem are,

- Blockage and Overflow of Sewage
- Corrosion of Sewers
- Deficient treatment unit at Ukkadam
- Heavy power charges
- Low Population Coverage by existing sewerage system
- Inadequate sewage farm at Ukkadam [54].

STORM WATER DRAINAGE

The Corporation maintains 585.22 km of storm water drains in the city. 50 Km of storm water drain have been constructed after 1999 and 45 km length of storm water drains have been constructed in flood prone areas. Among all the drains, the Sanganurpallam is the main drainage artery, which traverses from north to south with its outfall in Noyyal River. The drainage course is encroached upon by number of hutments. The Noyyal River forms the southern boundary of the Coimbatore Corporation and acts as a major drainage course carrying the storm water discharge. Most of the tanks are located in southern part of the city and finally drain into Noyyal River [54]. The city has a natural topography, sloping from North towards South and West towards East. The slope benefits storm water run-off and the path of natural drains facilitate draining of storm water.

The issues identified in the storm water drainage are

- Silting and Constriction due to weeding of major canals.
- Flooding of residential areas located along the course.
- Encroachments along the major canals have led to the weakening of the bunds which has also been one of the prime causes for such severe flooding.
- Disposal of solid waste into drainage channels [54].

SOLID WASTE MANAGEMENT

Solid waste management is carried out by the Health Department of Coimbatore Municipal Corporation. The details of the source of waste generation are presented in table no. 7.

Primary collection

Door to door collection of segregated solid waste is practiced for primary collections with 287nos. of pushcarts. Road sweeping and mopping is also carried out with 12 nos. of road sweeping flipper machines to clean the roads. Vegetable market waste is being collected in the night conservancy in south and west zones [54].

Secondary collection

There are four stations where the collected wastes are transferred. Secondary collection sites are

- Peelamedu,
- Ondipudur,
- Sathy Road,

Ukkadam [54].

Disposal sites

There are four disposal yards out of which only one is operational at Vellalore sewage farm. The corporation has obtained permission from the Tamil Nadu Pollution Control Board (TNPCB) to use the land for municipal solid waste disposal. The Vellalore compost yard has an extent of 604 acres of dry land acquired from farmers with one Weigh Bridge and 30 acres of greenery around it [54].

The issues identified in the present system are as follows.

Primary collection

- Source Segregation and house to house collection practiced in 10% area
- Uncontrolled littering along main roads, streets and Drains
- Present container capacity is enough only for 70% removal of the accumulated solid water
- Lack of adequate community participation in primary collection
- Mismanagement of the hired vehicles
- Lack of records to track hired and owned vehicles [54].

Secondary collection

- Inefficient fleet management system
- Lack of workshop facilities
- No Synchronized system between primary and bulk wastage storage facility
- Higher expenditure on maintenance of vehicles used in secondary transportation [54].

Processing and disposal of waste
- No scientific treatment and disposal of garbage
- Lack of adequate infrastructure in compost yard [54].

ENVIRONMENTAL IMPACTS IN THE CITY

Pollution is the major environmental issue faced by the city. The city is affected by air pollution, water pollution and waste management problems.

Water pollution

An analysis of nine water bodies of city by a local NGO indicates that most of the water bodies are contaminated. The discharge of industrial and domestic effluents, encroachments of tank and canal beds, reclamation and exploitation of ground water are some of the important factors causing damage to these water bodies. A key factor responsible for polluting the water bodies is the discharge of untreated effluents from small- scale industrial units lacking in adequate individual treatment facilities. Further, there is a risk of contamination to ground water, resulting from over exploitation of ground water by domestic and industrial users [54].

Air pollution

Air pollution in Coimbatore is caused due to vehicular emissions, industrial emissions and construction related activities. The Tamil Nadu Pollution Control Board limits its monitoring to the individual industry level and is specific for large industries alone [54].

Pollution from solid and hazardous wastes

The main causes for pollution include increasing household and commercial wastes as well as hazardous wastes from the industrial activities. Inability to dispose waste in a scientific manner has been a prime factor resulting in pollution. In addition, hazardous wastes and medical wastes are disposed along with the domestic waste without any separation at the source poses a potential health hazard. The disposal facilities at Mettupalyam Road and Ukkadam are devoid of facilities and the wastes are disposed in an unscientific manner. The city does not have a sanitary landfill and the disposal points are close to the residential areas causing potential danger to the health of the nearby residents [54].

SIRUTHULI'S CONTRIBUTION TO COIMBATORE CITY

SIRUTHULI is a Coimbatore based NGO established in the year 2003 with Ms. Vanitha Mohan as its managing trustee. The organization aims at establishing a greener Coimbatore city. With help from the Coimbatore Corporation, SIRUTHULI has implemented rain water harvesting structures in the city at large scale, which helped to improve the water table level gradually. For the purpose, seven lakes namely Krishnampathy, Narasampathy, Selvampathy, Kumarasamy, Selvachinthamani, Kurichi kulam and Coimbatore big tank have been de-silted and deepened. A February 2013 report in the Times of India states that the lakes in and around the Coimbatore city are slowly dying due to various reasons including dumping of waste in to the water bodies and construction of buildings along the lake beds [56]. Several initiatives are being taken by SIRUTHULI to protect the water resource of Coimbatore, the details of which are available at their official website (www.siruthuli.com).

COMPREHENSIVE WASTE MANAGEMENT PLAN FOR COIMBATORE CITY

From the case study, it is very clear that the current waste management system is not effective and the city struggles to dispose its waste. Hence, a proper scientific approach is needed to create a greener city. A comprehensive waste management plan is proposed as a schematic view (figure 2).

The main objectives of the proposed comprehensive waste management system are
- to process waste accordingly,
- to generate energy from waste,
- to utilize the generated energy,
- to extend the system beyond material / energy recovery and utilization,
- reducing pollution leading to a further greener environment.

In the proposed system, the process does not end with the production and utilization of energy. The system aims to reduce land filling as much as possible thereby, reducing the effects on environment. The output residual waste that is received after energy recovery would serve as input for various other processes such as the production of aesthetic value products. The output from solid waste processing for example, could serve as input/raw materials involved in building materials [57], packaging materials [58] and construction of roads. A study on treatment of dairy industry waste reveals the potentials of biosolids in industries, where the output from processed dairy waste is utilized as input material in another process i.e., in the production of enzyme. By this way, land filling could be reduced to a greater extent which in turn reduces pollution of land, leading to prevention of underground water contamination resulting in a further greener environment. When the waste water is treated and reused, dependency on underground water could also be reduced greatly which in turn restores environment.

A study done by Giugliano et al., evaluated material/energy recovery in integrated waste management systems, which considered two sizes of integrated waste management systems: a metropolitan area and an average province [58]. In the study, environmental analysis was conducted using Life Cycle Assessment methodology (LCA), for both material and energy recovery activities and the environmental impacts were also considered. The

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study revealed that the energetic and environmental benefits were higher than the energetic and environmental impacts both for the large and for the small IWMS, the benefits being high when food wastes excluded. The present work has similarities to the study done by Giugliano et al., in energy recovery and utilization. Giugliano et al. considered incineration for the recovery of energy whereas the present work focuses on biological methods for energy recovery which could lead to a much better environment. Apart from energy recovery and utilization, the present research work also considers the fate of residual waste which is the output material of waste processing. Alternative methods are suggested instead of land filling the output material, which could greatly help in the reduction of pollution and establishment of greener environment. Figure 3 shows the steps involved in the comprehensive waste management system. Figure 4 and figure 5 shows the treatment of municipal solid waste and municipal sewage waste respectively.

Table 2: Population, income levels, municipal solid waste generation and composition in the reference cities

City & Country	**Population**	**GDP (US$) per Capita/ country**	**Kg Per Capita/ year**	**Kg Per Capita/ Day**	**Paper**	**Glass**	**Metal**	**Plastic**	**Organic**	**Other**	**Total**
Rotterdam, Netherlands	582,949	46,750	528	1.4	27%	8%	3%	17%	26%	19%	100%
San Francisco, USA	835,364	45,592	609	1.7	24%	3%	4%	11%	34%	21%	100%
Tompkins County, USA	101,136	45,592	577	1.6	36%	6%	8%	11%	29%	11%	100%
Adelaide, Australia	1,089,728	39,066	490	1.3	7%	5%	5%	5%	26%	52%	100%
Belo Horizonte, Brazil	2,452,617	6,855	529	1.4	10%	3%	2%	11%	66%	9%	100%
Curepipe, Mauritius	83,750	5,383	284	0.8	23%	2%	4%	16%	48%	7%	100%
Varna, Bulgaria	313,983	5,163	435	1.2	13%	15%	10%	15%	24%	24%	100%
Canete, Peru	48,892	3,846	246	0.7	6%	2%	2%	9%	70%	11%	100%
Sousse, Tunisia	173,047	3,425	394	1.1	9%	3%	2%	9%	65%	13%	100%
Kumming, China	3,500,000	2,432	286	0.8	4%	2%	1%	7%	58%	26%	98%
Quezon City, Philippines	2,861,091	1,639	257	0.7	13%	4%	4%	16%	50%	12%	100%
Bengaluru, India	7,800,000	1,046	236	0.6	8%	2%	0%	7%	72%	10%	100%
Delhi, India	13,850,507	1,046	184	0.5	7%	1%	0%	10%	81%	0%	100%
Managua, Nicaragua	1,002,882	1,022	420	1.1	9%	1%	1%	8%	74%	6%	100%
Lusaka, Zambia	1,500,000	953	201	0.6	3%	2%	1%	7%	39%	48%	100%
Nairobi, Kenya	4,000,000	645	219	0.6	6%	2%	1%	12%	65%	15%	100%
Bamako, Mali	1,809,106	556	256	0.7	4%	1%	4%	2%	21%	52%	83%
Dhaka, Bangladesh	7,000,000	431	167	0.5	9%	0%	0%	4%	74%	13%	99%
Moshi, Tanzania	183,520	400	338	0.9	9%	3%	2%	9%	65%	12%	100%
Ghorahi, Nepal	59,156	367	167	0.5	6%	2%	0%	5%	79%	7%	99%
Average	**2,462,386**		**343**	**0.9**	**12%**	**3%**	**3%**	**10%**	**53%**	**18%**	
Median	**1,046,305**		**285**	**0.8**	**9%**	**2%**	**2%**	**9%**	**61%**	**12%**	

Source: Scheinberg et al., 2010.

Table 3: Waste management and recycling system components in reference cities.

City, Country	Drivers for development				
	Public health	**Environmental protection**		**Resource value**	
	Coverage of waste collection and Sweeping (%)	**Controlled disposal/ incineration of total disposed/ incinerated (%)**	**State-of-the art Land filling/ incineration of total disposed/ incinerated (%)**	**Materials recovered by formal sector (%)**	**Materials recovered by informal sector (%)**
Adelaide, Australia	100	100	100	54	0
Rotterdam, Netherlands	100	100	100	30	0
San Francisco, USA	100	100	100	72	0
Tompkins County, USA	100	100	100	61	0
Varna, Bulgaria	100	100	100	2	26
Belo Horizonte, Brazil	95	100	100	0.1	6.9
Canete, Peru	73	81	0	1	11
Curepipe, Mauritius	100	100	100	NA	NA
Kunming, China	100	100	100	38	NA
Sousse, Tunisia	99	100	100	0	6
Quezon City, Philippines	99	100	0	8	31
Managua, Nicaragua	82	100	0	3	15
Bengaluru, India	70	78	78	10	15
Delhi, India	90	100	0	7	27
Ghorahi, Nepal	46	100	100	2	9
Dhaka, Bangladesh	55	90	60	0	18
Nairobi, Kenya	65	65	0	NA	NA
Moshi, Tanzania	61	78	0	0	18
Lusaka, Zambia	45	100	100	4	2
Bamako, Mali	57	0	0	0	85
Average	**82**	**90**	**62**	**16**	**15**
Median	**93**	**100**	**100**	**4**	**11**

Source**:** Scheinberg et al., 2010.

Table 4: Comparison of 2011 and 2001 Coimbatore census

Description	2011	2001
Actual population	3,472,578	2,916,620
Male	1,735,362	1,482,228
Female	1,737,216	1,434,392
Population growth	18.46%	16.96%
Area sq. km	4,850	4,850
Density/km^2	748	631
Proportion to Tamil Nadu population	4.81%	4.67%

Source: Census 2011.co.in-population census India

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Table 5: Surface source details.

Sources	Unit	Details
Siruvani River		
Commissioned in	year	1982
Distance	Km	36
Designed Capacity	MLD	101
Daily Drawal	MLD	87
Transmission	-	Gravity
Pilloor Dam		
Commissioned in	year	1995
Distance	Km	95
Designed Capacity	MLD	131.25
Daily Drawal	MLD	65
Transmission	-	Pumping

Source: http://www.coimbatore- corporation.com

Table 6: Bore wells/Open wells operations

Zone	Private operation	Departmental operation	Total bore/open wells
	Nos.	Nos.	Nos.
North	75	51	126
East	55	41	96
West	55	42	97
South	65	52	117
Total	250	186	436

Source: http://www.coimbatore- corporation.com

Table 7: Waste generation in Coimbatore.

Waste Generated	MT	% of total waste
Domestic	349.54	58.16
Industries	18.39	3.06
Commercial and Others	39.25	6.53
Segregated waste from Market	193.88	32.26
Total	601.00	100

Source: http://www.coimbatore- corporation.com

COLLECTION AND SEGREGATION OF HOUSEHOLD WASTE

The waste should be segregated at the collection site itself before the accumulation of large amount of non segregated waste. This method would be very useful in saving time and energy. The domestic waste can either be collected by bin method or by door to door collection. In case of bin method, separate bins are to be placed for kitchen waste collection and other non degradable waste collection. Here the household member itself segregates the waste. In case of door to door collection method, the worker collects the waste and segregates at the site itself.

COLLECTION AND SEGREGATION OF INDUSTRIAL WASTE

The industrial effluent must be segregated and pre treated at the corresponding industries itself. Following this method would avoid excessive dumping of inappropriate industrial waste.

TRANSPORT OF WASTE

Domestic waste can be transported to the treatment site by huge waste carrying vehicles. Private partnerships can also be made for the purpose. Pre treated industrial organic waste can be transported through tanker Lorries or by sewage lines specific for industrial waste.

TREATMENT PLANT

The plant receives waste from the entire city. The municipal waste from sewage drains contains much water content and hence dewatering is to be done to obtain solid sludge that is to be treated separately. The plant must contain separate treatment facilities including

- Primary and secondary settling tanks
- Activated sludge tanks
- Composting tanks
- Anaerobic digestion tanks
- Incineration facility

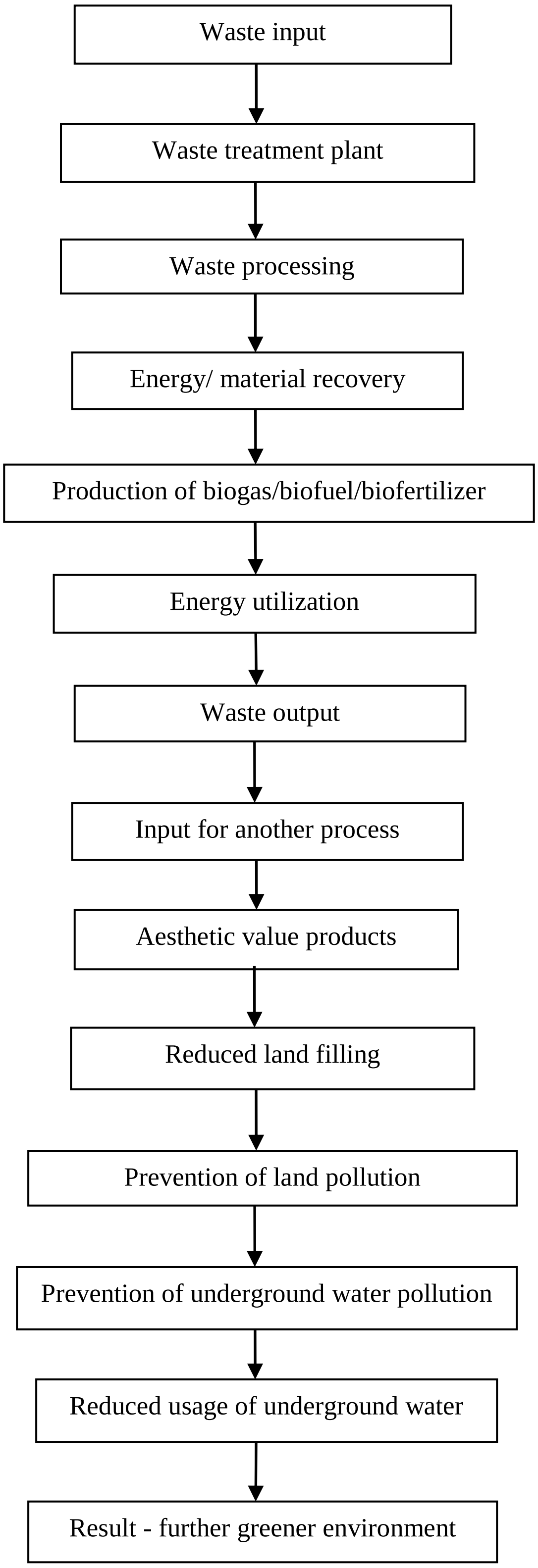

Figure 2: Process block diagram of comprehensive waste management system for Coimbatore city

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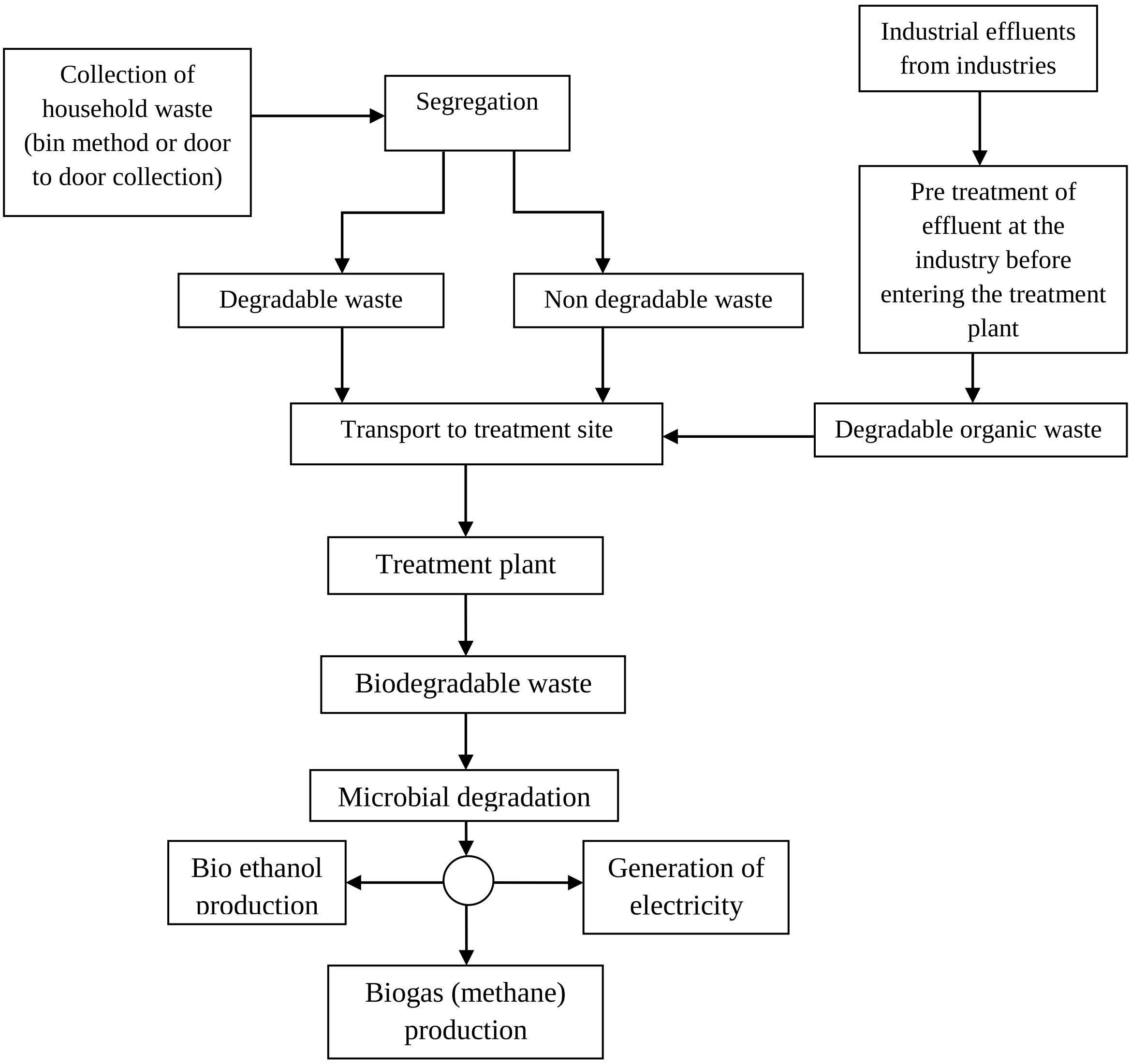

Figure 3: Steps involved in the comprehensive waste management system.

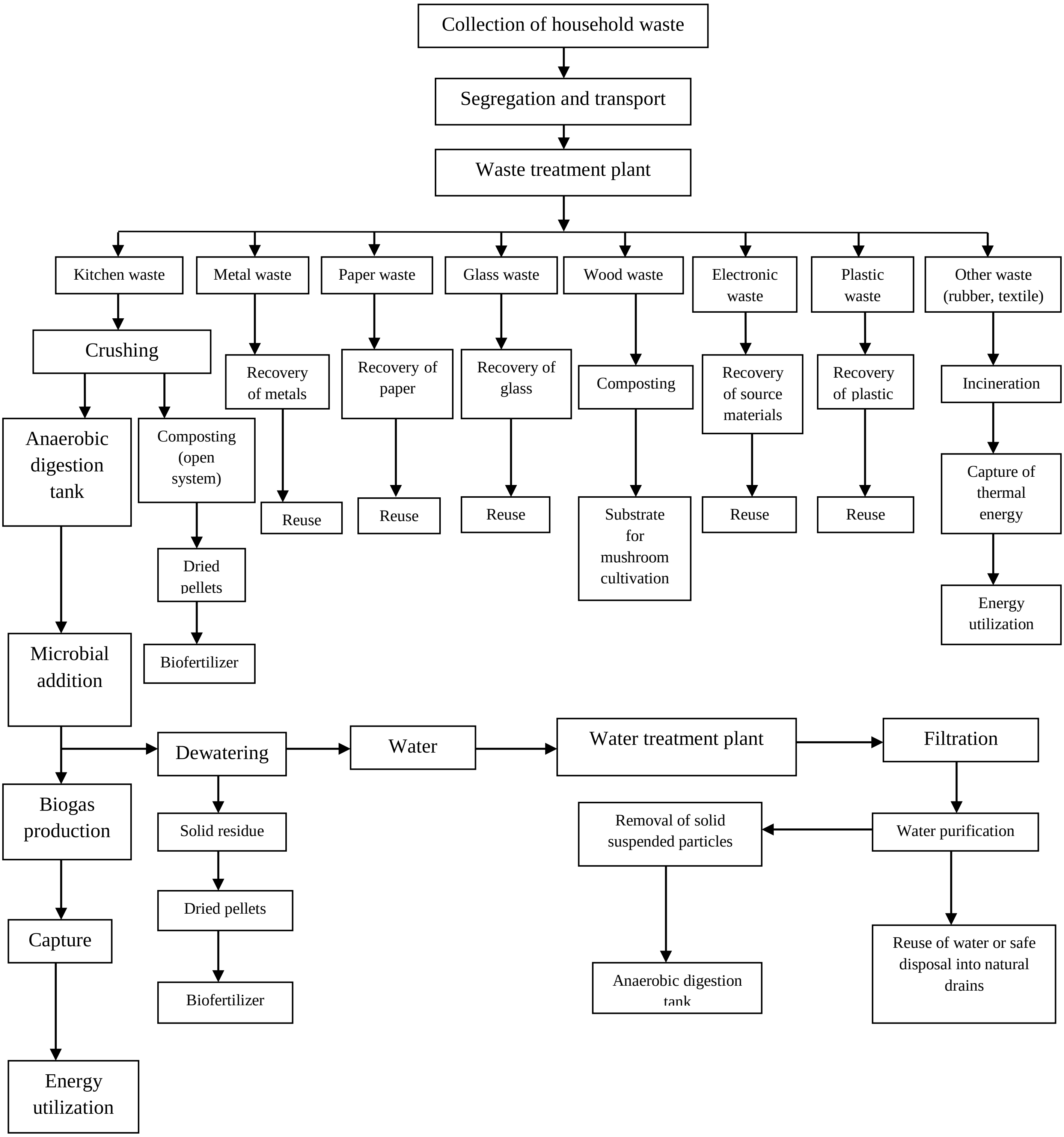

Figure 4: Treatment of municipal solid waste

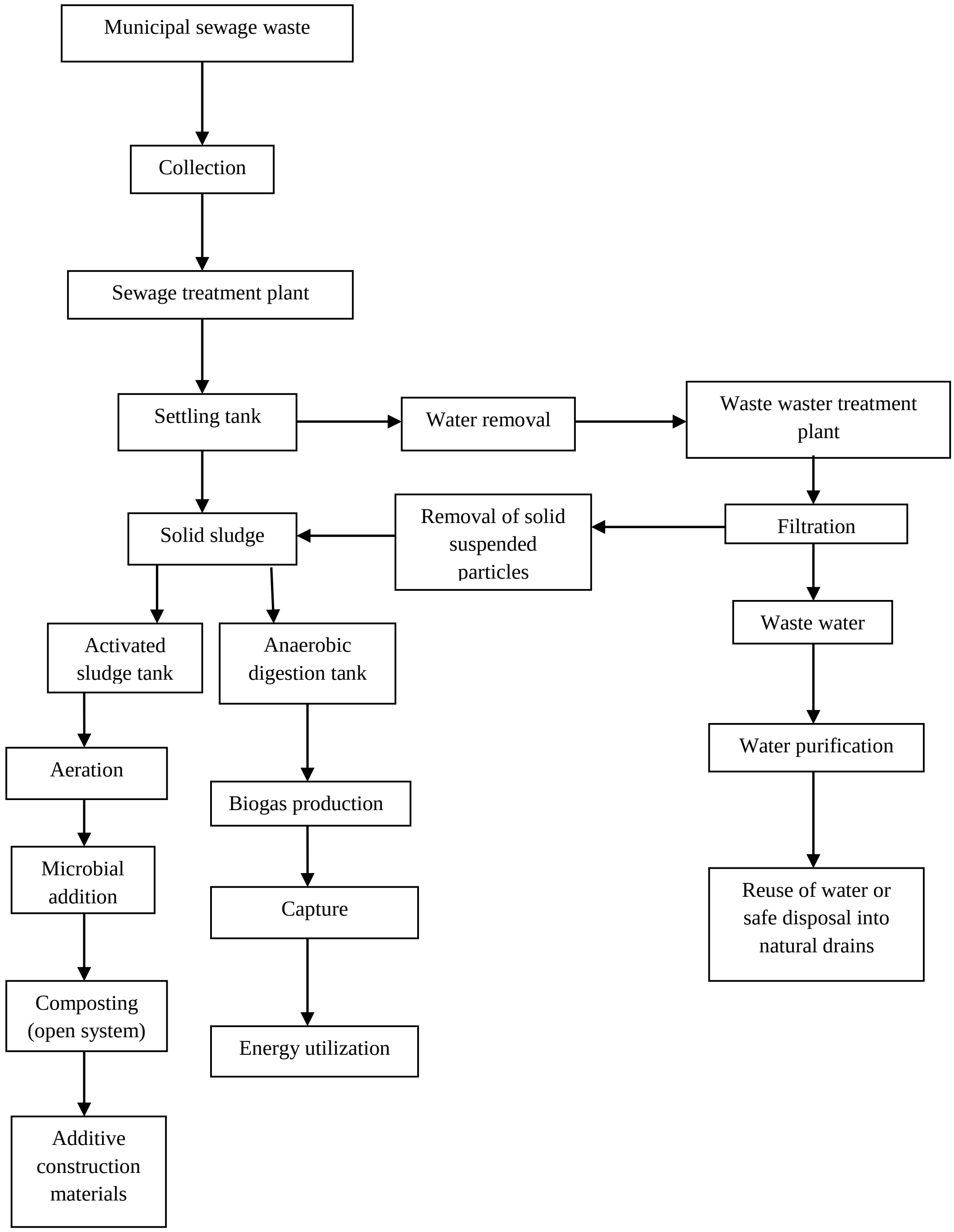

Figure 5: Treatment of municipal sewage waste

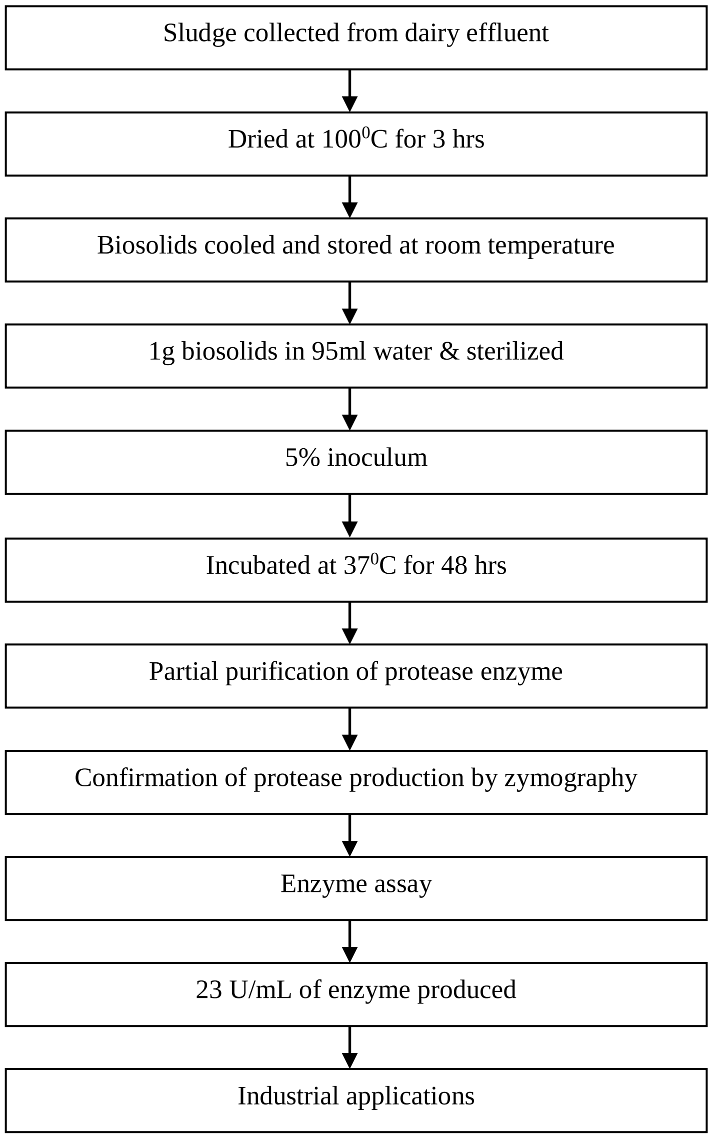

Figure 6: Schematic view of enzyme recovery from dairy waste.

ENERGY RECOVERY AND UTILIZATION

Solid waste is treated accordingly to recover energy. Various methods like composting, anaerobic digestion, heat drying and incineration can be adopted to recover bio ethanol, bio gas, bio electricity and other useful products. The recovered energy can in turn be utilized to run the treatment plant.

Enzyme recovery from dairy waste

An attempt was made to utilize dairy industry waste in the production of protease which is an industrially important enzyme. Dairy industry effluent was processed into biosolids. Biosolids finds a number of applications that include land reclamation, mine reclamation, agricultural land fertilization, forest fertilization, erosion control, horticulture, slope stabilization and roadside aesthetic improvements. Indirectly, biosolids is used as feedstock in the fabrication of value-added products such as compost, soil amendment mixes and fabricated soils. The processed biosolids was then utilized as substrate material for the growth and reproduction of *Bacillus subtilis*, a bacterium that produces extra cellular protease enzyme.

Method

The dairy industry sludge was converted into biosolids by means of direct heat drying process (150°C for 3 hours) as per FDA standards. One gram of the heat dried biosolids served as substrate for the preparation of basal media and the production of Protease by replacing conventional Carbon, Nitrogen sources and trace elements. The substrate was sterilized and seeded with 5% inoculum. They were incubated at 37ºC for 48 hours. The amount of total protein and Enzyme produced from the substrate was estimated [59].

Partial purification of protease enzyme

The crude enzyme obtained is partially purified by the following techniques.

Ammonium sulfate precipitation and dialysis

Ammonium sulfate was added to the cell free culture suspension up to 55% w/v of its saturation [60]. After 24 hours in the cold room the mixture was centrifuged at 10000 rpm for 10 minutes to separate the precipitate. The pellet was re-suspended in 2 ml of 0.2M Tris- HCl (pH 8) and dialyzed overnight against the same buffer with buffer changes of at least three times.

Polyacrylamide gel electrophoresis and zymography

Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) was carried out according to the method of Laemmli (1970) [61]. SDS-PAGE zymography was performed by modified method of Mary *et al* (2005) [62]which was not boiled and it was electrophoresed at 4°C and 20 mA through a 10% SDS-polyacrylamide gel containing 0.1% gelatin. SDS was removed by washing twice with 2.5% Triton X-100 for 20 minutes. Each gel was washed and incubated in 50 mM Tris-HCl (pH 8.0), 150 mM NaCl, 10 mM $CaCl_2$, and 1 μM $ZnCl_2$ at 37°C for 48 hours. The gel was stained for 20 minutes in 0.5% Coomassie brilliant blue R-250 in glacial acetic acid: isopropanol: DH_2O (1:3:6). Washing with distilled water revealed clear bands, where proteolysis of gelatin occurred, on a blue background.

Production of enzymes from dairy industry biosolids as substrates

The basal media amended with 1% heat dried biosolids showed good result comparably with conventional nutrient agar media for the growth of proteolytic bacterial strain. Similarly in production of protease, the unconventional biosolids showed the production of 23 U/ml of enzyme during 48 hrs of incubation which was comparably appreciable than the result of conventional substrates. Further standardization is required for its better production. Biosolids contain nutrients, organic matter and microorganisms that can provide benefits to soil [63] and has proven as effective substrate for the production of protease. Schematic view of enzyme recovery from dairy waste is shown in figure 6.

Recovery of biofuel

Biofuels are renewable, generally derived from agricultural crops such as corn, soybeans and sugarcane, or from biomass resources [64], such as agricultural, wood, animal and municipal wastes. Waste containing high amount of lignocellulosic material can be converted [65] into bio fuels. The two most common transport biofuels are ethanol and biodiesel. They are considered to be eco friendly and can be used as substitutes for petrol and diesel.

Energy recovery from municipal solid waste (MSW)

Energy can be recovered from MSW in the form of biogas and biofuel. The MSW can be processed into Refuse derived fuel (RDF) for generation of steam through boilers. The energy content of the MSW is calculated by the modified Dulong’s formula [66] given by,

$$\text{Energy content (Btu/lb)} = 145C + 610 (H2 – \{O2/ 8\}) + 40S + 10N$$

Where, C, H_2, O_2, N, and S represent the weight of carbon, hydrogen, oxygen, nitrogen and sulphur in the MSW respectively.

The theoretical energy content or Calorific Value (CV) of the MSW is calculated as 3750 Btu/lb (8723 KJ/Kg) [67].

Recovery of Biogas from MSW

Biogas is produced by controlled anaerobic decomposition of MSW. Methane and Carbon dioxide are the main components of biogas where, methane alone constitutes about 50-55% by volume [68]. The typical CV of biogas reported is 4713 Kcal/Kg (8950 KJ/Kg) [69]. The average BG generation rate from MSW under Indian conditions is estimated at 250 m^3/tonne of MSW and the average yield period of BG under Indian conditions is expected to be 7-10 years [68], only when a large portion of MSW consists of rapidly decomposable food wastes having a biodegradability of 0.82 [66]. The biodegradability is defined based on Volatile Solids (VS) content of the organic fraction of MSW. The lignin content (LC) of VS expressed as a percent of dry weight is used to estimate the biodegradable fraction. Mathematically, the biodegradability is defined by the following equation,

$$\text{Biodegradability} = 0.83 – 0.028\ LC$$

Recovery of biofuel from MSW

MSW can be fired in a boiler to generate steam. The steam can be converted to electric power through steam turbines. The MSW can be mass-fired, as received or processed (RDF) before firing. However, the boiler is to be fitted with pollution control equipment to reduce the generated gaseous and particulate emissions [66].

CONCLUSION

The proposed comprehensive plan is an eco-friendly, total waste management system. The system is designed to ensure efficient waste management right from waste collection, segregation, treatment to disposal and beyond that, the fate of the land filled residue. Recovery of energy and material from waste would be maximum in the system as the residual waste output is treated as greener input raw material for another polluting process making it more greener. This system would thus allow minimum level of land fills, minimizing leachate induced under ground water pollution. Hence, scientific way of handling waste would result in a less pollutant neighbourhood, capable of providing pollutant-less surface water thereby, reducing the load on ground water. The huge benefit of the plan would be the establishment of greener environment apart from energy recovery and it can be adopted with slight modifications for all cosmopolitan cities around the world with high pollution levels consequently making the world greener and less polluting.

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